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ENHANCEMENT OF HEAT TRANSFER FOR AIR FLOW THROUGH A DUCT WITH VARIOUS RIBS

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ABSTRACT

In this study heat transfer and thermal performance characteristics in the pipe flow with three types of ribs tubes (square, circular, elliptic) at constant wall flux condition was studied for Reynolds number ranges from 5000 to 15000 to investigate the effect of the rib shapes on heat transfer. The renormalization group k-ε model is used to simulate turbulence in ANSYS - FLUENT 6.3. Results of temperature and velocity distribution along the tube for the case of tube with internal ribs were compared with that of smooth tube, these results show that the use of internal ribs enhance the heat transfer rate and found to possess the highest performance factors for turbulent flow.

KEYWORDS: CFD, Heat Transfer Enhancement, Internal Ribs, Turbulators and Turbulent Flow

INTRODUCTION

Energy plays key role for economic and social development. Demand for energy has been rising rapidly with growing population, transportation and industrialization [1]. Heat transfer enhancement or heat transfer intensification is of very importance in the applications of thermal systems where overheating can damage the components or assemblies of the system. Hence, in order to avoid such type of problems, some heat transfer intensification techniques are being used in industrial applications [2]. Heat transfer enhancement technology is the process of improving the performance of a heat transfer system by increasing the convection and radiation heat transfer coefficients. Over the past forty years, this technology has been extensively used in heat exchangers and other heat transfer equipment in thermal power plants, chemical processing plants, air conditioning equipment, refrigerators and vehicle radiators [3].Flow over bluff body is important in many engineering application. Most researchers focused on the flow over cylinder and square. For the flow past the cylinder, the vortices are shed with natural frequency and vortex shedding can be controlled by oscillation of cylinder [4]. The efficiency of compact heat exchangers can be improved for example by means of boundary layer modification and active surface enlargement. Ribs can be used to induce turbulence and thus enhance the heat transfer. The optimization of heat exchangers therefore always has to be aimed at an increase of the heat transfer simultaneously with a minimum increase of pressure drop. Heat transfer enhancement by means of various techniques is an important task for research, which is also paid tribute to by the huge and growing number of publications on this subject, especially in recent times[5].The increasing necessity for saving energy andmaterial caused by the world resource shortage andenvironmental concerns has prompted to develop moreeffective heat transfer equipment. Ribs are often used to enhance forced convectiveheat transfer between the wall and fluid because they cause flow separation and reattachment, consequently resulting in destroying the laminar sub-layer [6]. A review of literature shows that various researchershave attempted to improve the heat transfer enhancement.

Kaewkohkiatet al [7] experimentally studied on the heat transfer and friction characteristics in a rectangular

channel with rib-groove turbulators and reported thatboth Nusselt number and friction factor increase with decreasing pitch ratio.

Bilenet al [8] experimentally studied heat transfer and friction characteristics of a fully developed turbulent air flow in different grooved tubes (circular, trapezoidal and) and reported that heat transfer enhancement is up to 63% for circular groove, 58% for trapezoidal groove and 47% for rectangular groove, in comparison with the smooth tube at the highest Reynolds number of 3800.

TANG Xinyi and ZHU Dongsheng [6] studied the turbulent flow and heat transfer enhancement in ducts or channels with rib, groove or rib-groove tabulators .They found that lower Reynolds number (Re) gives higher enhancement index and as compared to smooth duct, all rib-groove arrangements significantly enhance the heat transfer up to 80%, 60%, and 46%, respectively with use of tabulators. The friction factors were found to be approximately 6.9, 5.5 and 4.8 times above the smooth duct, respectively.

RajendraKarwa and B. K. Maheshwari [9] studied the heat transfer and friction in an asymmetrical rectangularduct with some solid and perforated baffles with relative roughness. The friction factor for the solid baffle was found between 9.6-11.1 times than smooth duct which decreases in perforated baffle. The baffle which has an openarea gives the highest heat transfer.

SooWbanAbn and Kang Pil Son [10] found that the heat transfer can be enhanced by the use of rough surfaces. Four different shapes such as semicircle, sine wave, trapezoid, and arc were suggested to investigate the heat transfer enhancement and friction factor on rectangular duct. They measured the friction factor and heat transferenhancement on smooth duct and compared it with the results. Square shape geometry gave the highest value because of its strongest turbulence mixing caused by rib. Non circular ducts such as equilateral triangle, Square and rectangular ducts have lower frictional factors and heat transfer as compared to circular ducts this increase in thefriction factor and heat transfer depends upon properties and size of the fluid molecules.

Liou et al. [11] studied ribbed surfaces numerically and experimentally, using the k--A algebraic stress and heat flux model and LDV measurements. Theyfound good agreement between modeling and experimentation for a 2D case

Archarya et al. [12] applied both linear and nonlinear k-_ models to successive two-dimensional rectangular ribs and found that the performance of the two models was similar, except that the nonlinear model produced more realistic Reynolds stress distributions than the linear form in the region immediately above the ribs.

During the last two decades, computational fluid dynamics (CFD) has become a very powerful tool in the process of industries not only for the researchand development of new processes but also for the understanding and optimization of existing one.

The present work a CFD modeling was carried out in order to find out the heat transfer in a tubeequipped with ribs. In this paper study the pipe flow with three types of ribs tubes (square, circular, elliptic) at constant wall flux condition was studied for Reynolds number ranges from 5000 to 15000 to investigate the effect of the rib shapes on heat transfer. The thermal hydraulic performance for all the cases was also performed.

CFD METHODOLOGY

In this investigation a 2-D numerical simulation of the conjugate heat transfer was conducted using the CFD code FLUENT 6.3. The CFD modeling involves numerical solutions of the conservation equations for mass, momentum and energy. These three equations are used to model the convectiveheat transfer process with the following assumptions, (a) steady 2-D fluid flow and heat transfer, (b) incompressible fluid and flow, and (c) physical properties of cooling fluid are temperature dependent. These equations for incompressible flows can be written as follows:

2.1 Mass Conservation

$$\frac{\partial(\mathrm{ui})}{\partial \mathrm{xi}} = 0 \tag{1}$$

2.2 Momentum Conservation

$$\frac{\partial(ui)(uj)}{\partial\, xj} = -\frac{\partial p}{\partial xi} + \frac{\partial}{\partial xj}\left[\mu \frac{\partial(ui)}{\partial xj} + \frac{\partial(uj)}{\partial xi} - \rho(ui\; uj)\right] + \rho gi \tag{2}$$

2.3 Energy Conservation

$$\frac{\partial}{\partial xi}\big((ui)(\rho E + p)\big) = \frac{\partial}{\partial xi}(k_{eff}\frac{\partial T}{\partial xi} + u_j\;(\tau_{ij})_{eff}) \tag{3}$$

2.4 Boundary Conditions

The boundary zone location is specified in the GAMBIT itself; the inlet, outlet and the wall condition location is specified.

2.5 Fluid Entry Boundary Condition

The inlet air flow with Re (5000, 7500, 10000, 12500, 15000) and constant temperature of 273 K

2.6 Wall Boundary Conditions

The wall is provided with wall boundary condition, a constant heat flux (2500 W/m^2) is provided for plain andribbed tube.

RESULTS AND DISCUSSIONS

In present work following the simulation methodology and utilizing the boundary conditions as mentioned in detail in Section 2, simulations were completed to obtain following results:

Figures (1-a),(1-b), (1-c) and (1-d) show the contours of temperature distribution along the whole test section geometry at constant heat flux(2500 W/m^2) for smooth and three types of ribs tubes (square, circular, elliptic) for Reynolds number 5000 to investigate the effect of the rib shapes on heat transfer respectively .

Figures (2-a),(2-b), (2-c) and (2-d) show the contours of temperature distribution along the whole test section geometry at constant heat flux(2500 W/m^2) for smooth and three types of ribs tubes (square, circular, elliptic) for Reynolds number 10000 to investigate the effect of the rib shapes on heat transfer respectively .

Figures (3-a),(3-b), (3-c) and (3-d) show the contours of temperature distribution along the whole test section geometry at constant heat flux(2500 W/m^2) for smooth and three types of ribs tubes (square, circular, elliptic) for Reynolds number 15000 to investigate the effect of the rib shapes on heat transfer respectively .

It shows that the pipe with ribs has highest outlet air temperature. This means that the pipe with ribs, has highest surface area resulted in enhancing the heat transfer.

Figure (4-a),(4-b), (4-c) and (4-d) shows the contours of velocity distribution and stream line along the pipe for four cases, one without ribs and the other with ribs at constant heat flux(2500 W/m^2) and Reynolds number 10000 . It shows that the pipe with internal ribs having more velocity distribution than the case of smooth pipe. This because of the swirls generated from the use of opened rings.

Figure (5-a),(5-b), (5-c) and (5-d)shows the contours of velocity distribution and stream line along the pipe for four cases, one without ribs and the other with ribs at constant heat flux(2500 W/m^2) and Reynolds number 15000 . It shows that the pipe with internal ribs having more velocity distribution than the case of smooth pipe. This because of the swirls generated from the use of opened rings.

Figure (6),(7), (8) and (9) shows the temperature distribution along the pipe for four cases, one for smooth and three types of ribs tubes (square, circular, elliptic) for Reynolds number 5000 to 15000. It shows that the pipe with ribs has highest outlet air temperature. This means that the pipe with ribs, has highest surface area resulted in enhancing the heat transfer.

The effectiveness was indexed by the ratio of the heat transfer coefficient of the ribs tube to that of the smooth tube in terms of h/h_o .As shown in figure. (10) the h/h_o ratio at different fluid flow rates was lower for the square ribs tube when compared to other ribs tubes. The results show that at some Reynolds numbers the reported values of h/h_o for elliptic ribs tube were more than that of other ribs tube.

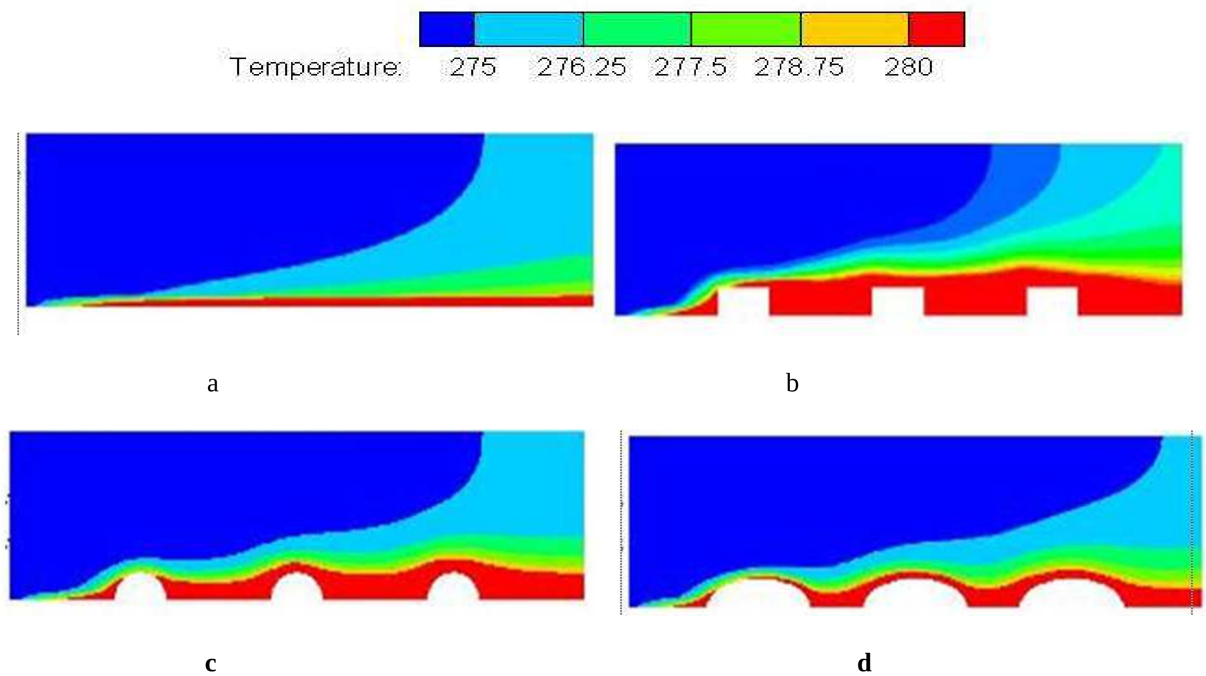


Figure 1 Contour of Temperature Distribution at Re=5000

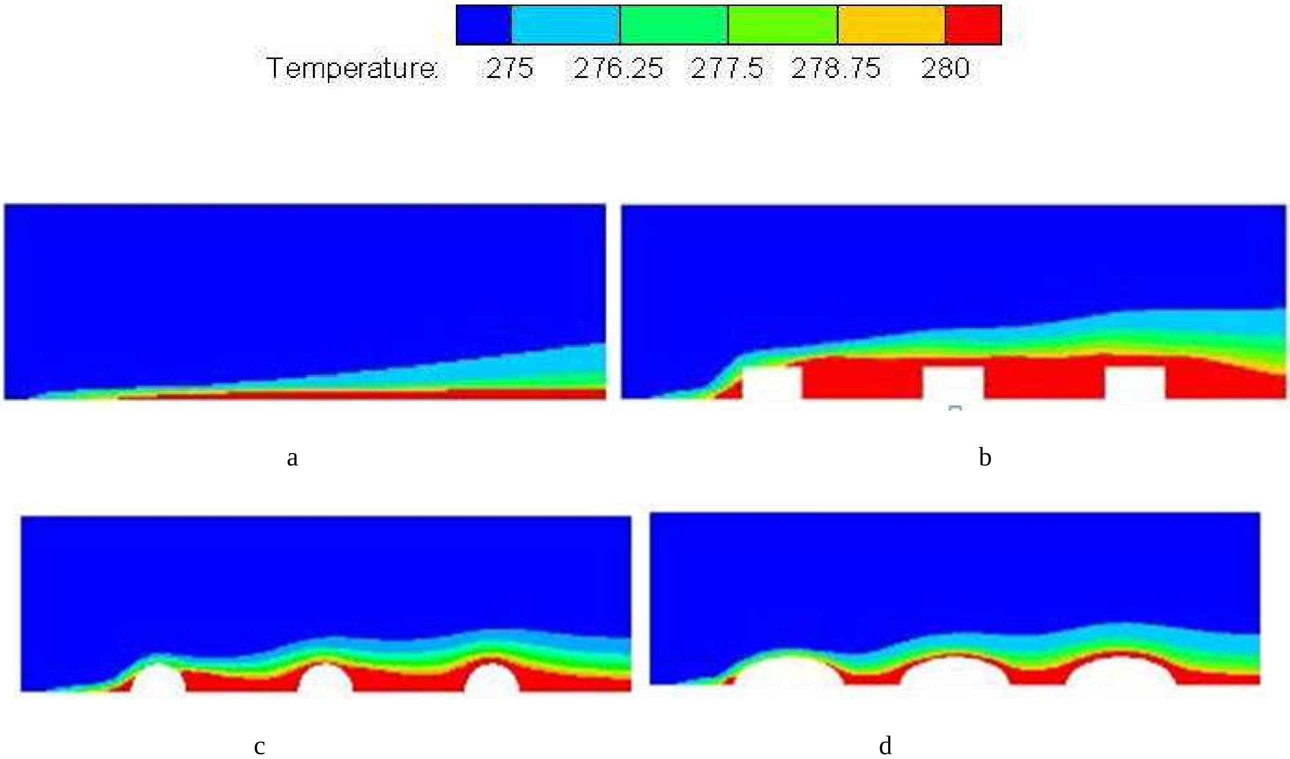


Figure 2 Contour of Temperature Distribution at Re=10000

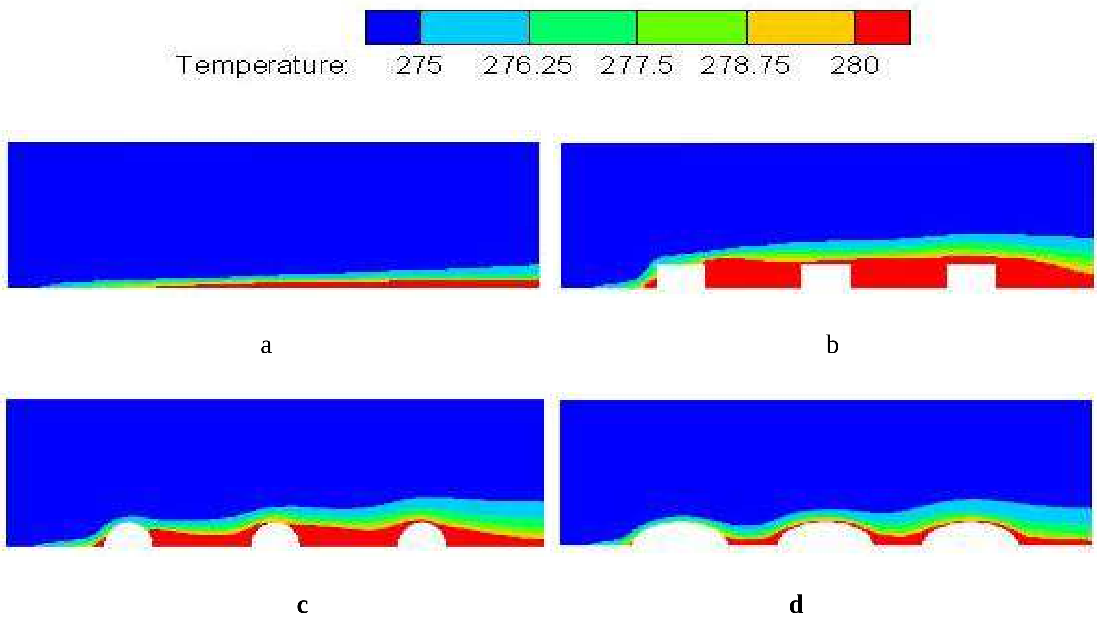
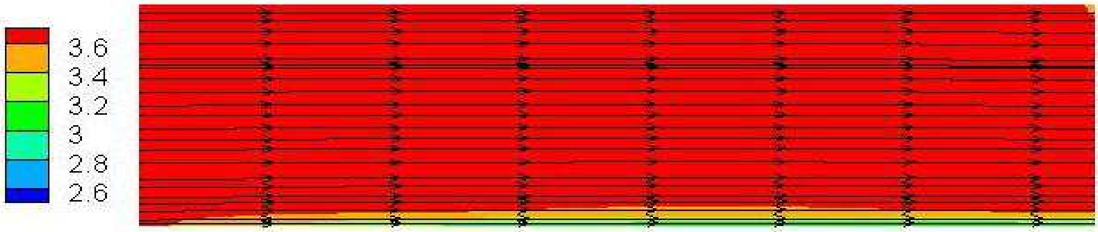
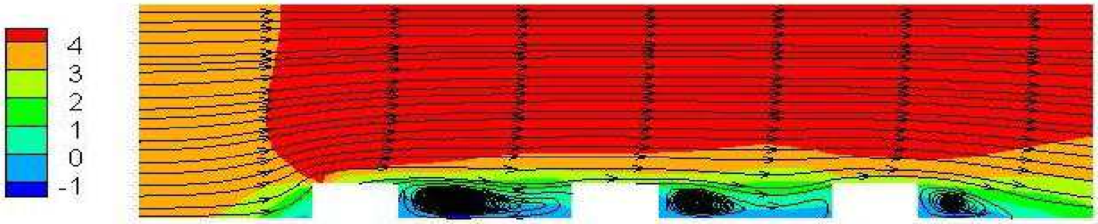


Figure 3 Contour of Temperature Distribution at Re=15000



a



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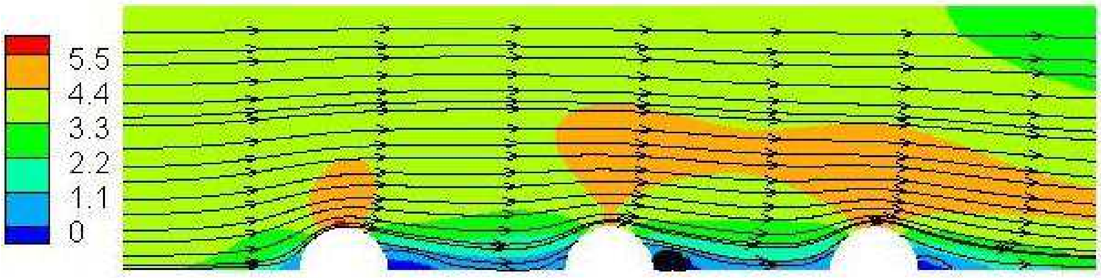
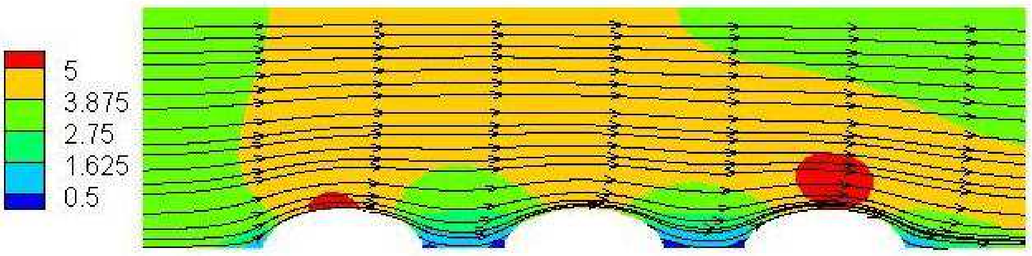
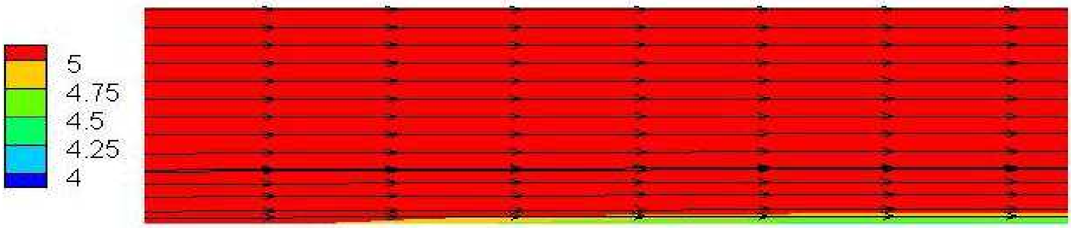


c

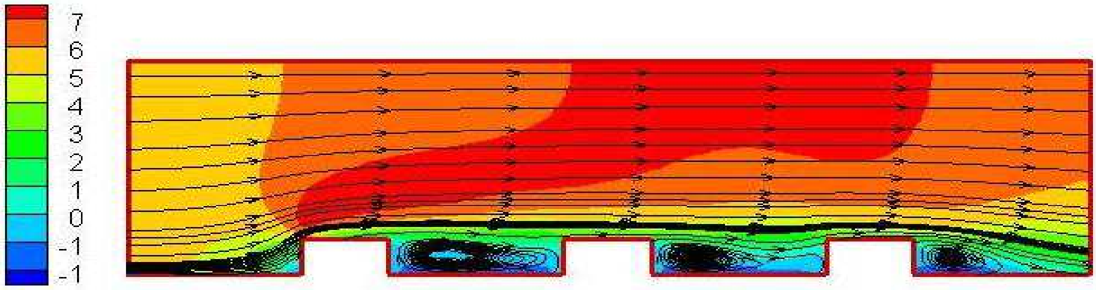


d

Figure 4 Contour of Velocity Distribution at Re=10000



a



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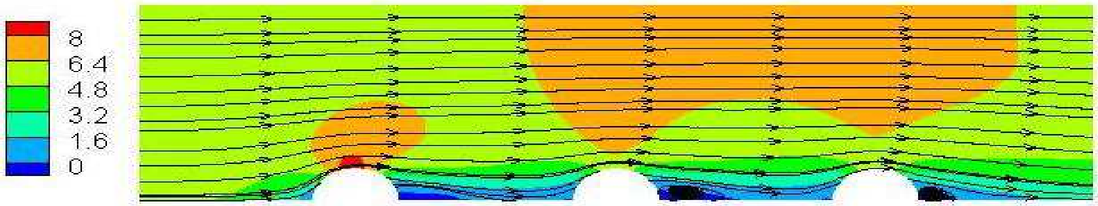

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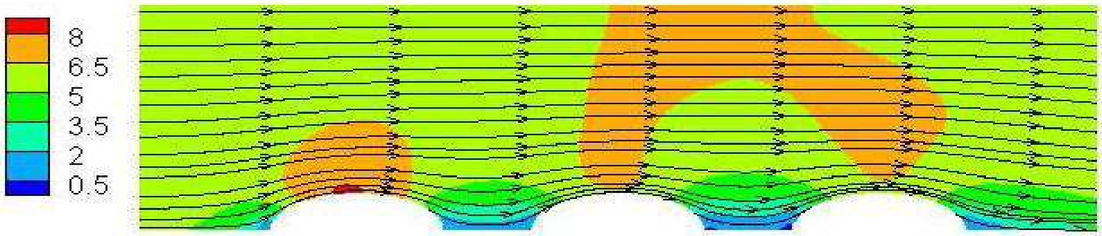

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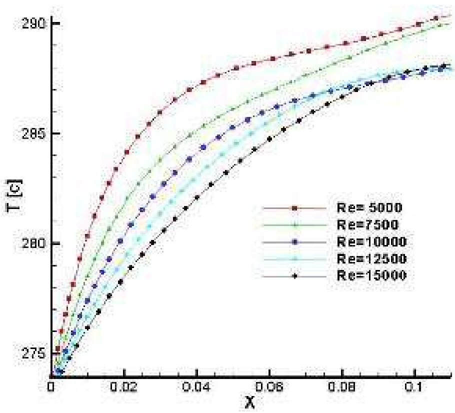
Figure 5 Contour of velocity Distribution at Re=15000



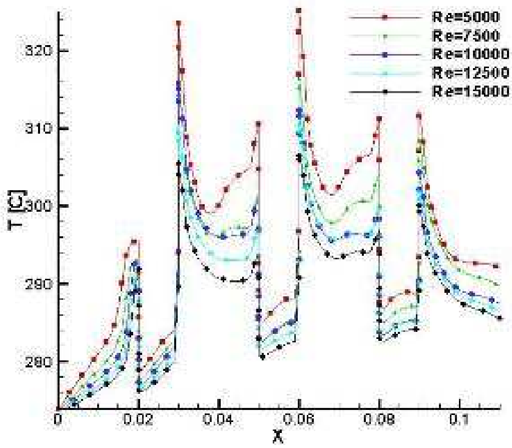
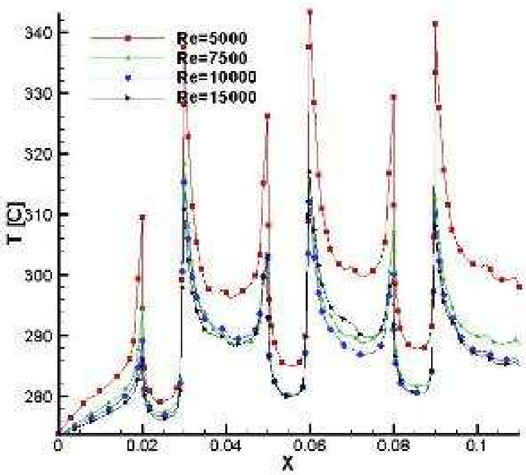


Figure 6 Variation of Temperature along the smooth Tube.	**Figure7 Variation of Temperature along The Tube with square rib**



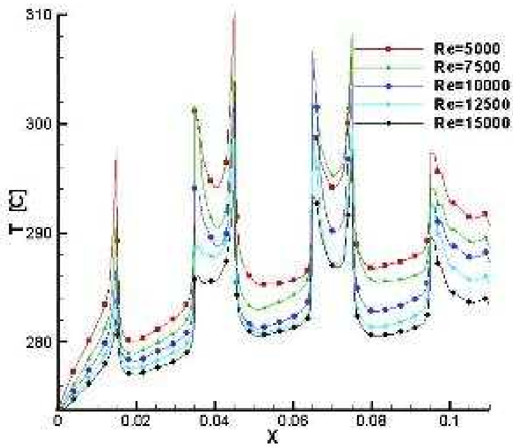


Figure 8 Variation of Temperature along The Tube with elliptic rib	Figure 9 Variation of Temperature along the Tube with circular rib

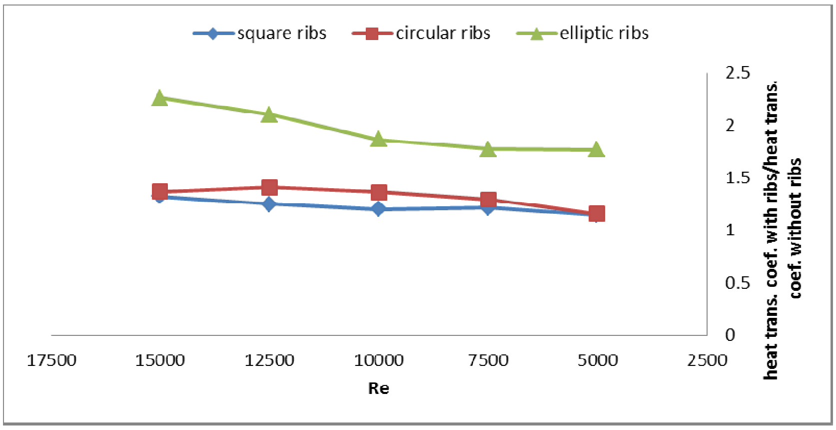


Figure 10 Effectiveness h/ho vs. Reynolds number for Various Ribs

CONCLUSIONS

Numerical simulation has been presented on heat transfer characteristics for the flow of cooling air in heated tube under steady state turbulent flow. The Fluent® was used for modeling and CFD analysis in the present work. The different geometry ribs tube like circular, square and elliptic were introduced for this analysis. The CFD code might serve as a powerful tool to assess the heat transfer characteristics for turbulent flow inside the tubes. The following conclusions can be drawn from the present study:

- CFD predictions were shown to reproduce the enhancement in heat transfer for the use of internal ribs, with respect to the smooth tube.
- Based on CFD analysis, higher thermal hydraulic performance were obtained for the tube with ribs than the tube without ribs.
- Tube with ribs gave more velocity disturbance than the tube without ribs.
- Heat transfer coefficient increases with the increase of Reynolds number.
- The pipe with ribs has highest outlet air temperature. This means that the pipe with ribs, has highest surface area

resulted in enhancing the heat transfer.

- The results show maximum value of heat transfer coefficient happens at the Tube with elliptic ribs.

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